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Lu-Hf and Sm-Nd geochronology of garnet gneisses in the central Appalachians, U.S.: Implications for the timing and duration of Grenville Orogeny

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The Grenville orogeny is one of the most significant geological events in Earth's history with remnants of this event prominent on virtually every continent. Constraining its timing and duration is important not only for understanding the tectonics of the Grenville itself, but also for understanding supercontinent cycles and other questions of Earth's evolution. In order to provide better constraints on the timing of Grenvillian metamorphism, we analyzed garnet-bearing Mesoproterozoic ortho and paragneisses, collected along a 150 km transect in the northern Blue Ridge Province, using combined Lu-Hf and Sm-Nd geochronology. The orthogneisses have U-Pb zircon crystallization ages of $\sim$1140 and 1100 Ma. The paragneisses have maximum depositional ages $\sim$1050 to 1020 Ma, based on the youngest detrital zircon populations. Zircon overgrowths and monazite ages suggest metamorphic events between $\sim$1050 and 960 Ma. The Lu-Hf and Sm-Nd data for these samples both yield robust garnet ages with large spread of parent/daughter ratios, low age uncertainties, and low MSWD values. Lu-Hf ages define a narrow time span (1043$\pm$12 Ma to 1016$\pm$4 Ma; wtd. mean, 1024$\pm$7 Ma, 2σ). The Sm-Nd ages, determined on the same solutions as Lu-Hf, also define a narrow time range but are systematically younger (974$\pm$11 Ma to 932$\pm$5 Ma; wtd. mean, 957$\pm$10 Ma). The average difference between Lu-Hf and Sm-Nd ages is 67 Ma; the oldest Sm-Nd age is 40 Ma younger than the youngest Lu-Hf age. These large systematic differences in the ages are enigmatic. While Sm-Nd ages younger than Lu-Hf are not uncommon, these differences are typically small. There are, however, potential explanations for these differences. (1) Lu partitions strongly into garnet during growth resulting in high Lu/Hf ratios in the core and yielding ages weighted toward the beginning of growth (e.g., Skora, 2006); no similar partitioning exists in Sm/Nd and these ages reflect mean garnet growth. (2) Lu diffuses much faster than Hf at elevated temperatures resulting in Lu diffusing from high Lu regions after garnet formation, potentially leading to anomalously old ages (e.g., Ganguly et al., 2011). (3) The Lu-Hf system has a higher closure temperature than Sm-Nd (e.g., Scherer et al., 2001; Smit et al., 2013) and younger Sm-Nd ages could reflect a later start of their isotopic clocks. Based on our data, the first two explanations are unlikely to generate large and systematic differences in the ages. None of the Blue Ridge garnets have significant Lu/Hf or Sm/Nd zoning, which likely indicates equilibration of the garnets subsequent to their growth; differences in elemental partitioning during garnet growth cannot explain the age differences. The Lu-Hf ages, while much older than the Sm-Nd ages, are not anomalously old and overlap with the timing of zircon growth. Ti-in-quartz thermometry performed on 7 samples yield a weighted average temperature of 828$\pm$54°C which broadly overlaps with estimates from the Ti-in-zircon thermometer by Tollo et al., (2010) of 740$\pm$40°C. Therefore, we interpret the younger Sm-Nd ages as due to differences in closure temperatures; the Lu-Hf system closed soon after garnet growth at $\sim$1024 Ma whereas Sm-Nd closed at $\sim$ 970 to 930 Ma. These data require that the rocks remained at elevated temperatures and pressures for tens of millions of years, presumably deep within thickened crust, during the culmination of the Grenvillian orogeny.